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Psora taurensis (Psoraceae, Lecanorales), a new lichen species from Turkey

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Abstract

Herein we describe the new species, *Psora taurensis*, from two localities in the Taurus Mountains in Turkey at ca. 1000 m altitude. Investigations of anatomy, secondary chemistry and DNA sequences (ITS and mtSSU) of *P. taurensis* and presumed close relatives suggest that *P. taurensis* is a distinct evolutionary lineage with *P. tenuifolia* as its sister, although it is morphologically more similar to *P. russellii* and *P. vallesiaca*.

Key words

Anatomy, DNA, phylogeny, Lecanorales, lichenized ascomycetes, taxonomy, TLC, Turkey

Introduction

After publication of our recent paper on *Psora altotibetica* Timdal et al. (Timdal et al. 2016; see this paper also for a general background on the genus), we sequenced an unidentified specimen of *Psora* collected by one of us (ET) in the Taurus Mountains in Turkey in 1994. Based on morphology and secondary chemistry, it had been suspected to be related to the North American *P. russellii* (Tuck.) A.Schneider, but DNA sequence data from the internal transcribed spacer region (ITS) suggested a closer relation to the *P. altotibetica–tenuifolia–vallesiaca* clade, recovered by Timdal et al. (2016: fig. 1). Independently, AMK had sequenced the ITS region from a second spec-

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imen, which had been collected some 150 km east-southeast in the same mountains by MGH in 2012. A preliminary comparison of the two DNA sequences suggested we had collected the same species. The aim of the present study was to further investigate the relatedness and shared distinctness of these two specimens in a broader phylogenetic context that includes presumed closely related species and an additional and more conserved genetic region, the mitochondrial ribosomal small subunit (mtSSU).

Material and methods

The specimens

This study is based on: (1) the two specimens of *Psora taurensis* referred to above, (2) the specimens with DNA sequence data in Timdal et al. (2016), (3) five additional *Psora* specimens deposited in O and sequenced for this work, and (4) two additional specimen of *Psora testacea* Hoffm., from which ITS sequences were available from GenBank. DNA sequence data for *P. elenkinii* Rass. and *P. pseudorussellii* Timdal is herein provided for the first time. Voucher data, major lichen substances, and GenBank accession numbers for these 42 specimens are given in Table 1. With the exception of three specimens, *P. himalayana* (C.Bab.) Timdal 1, *P. testacea* 2, and *P. testacea* 3, we have examined all collections listed in Table 1 by morphology and secondary chemistry during this project or previously.

Anatomy

Microscope sections were cut on a freezing microtome at 16 µm and mounted in water, 10% KOH (K), lactophenol cotton blue, a modified Lugol's solution in which water was replaced by 50% lactic acid, as well as 25% sulphuric acid, and chlor-zinc-iodine. Amyloid reactions were observed in the modified Lugol's solution after pretreatment in K. Chlor-zinc-iodine was used to locate remnants of algae in the cortex, and polarized light was used to locate crystals of secondary metabolites and calcium oxalate. Calcium oxalate was identified by adding 25% sulphuric acid to the section; the oxalate crystals dissolve and needle shaped crystals of calcium sulphate precipitate. Ascospore measurements are given as $X \pm 1.5 \times SD$ rounded to 0.5 µm, where X is the arithmetic mean and SD the standard deviation.

Secondary chemistry

Thin-layer chromatography (TLC) was performed in accordance with the methods of Culberson (1972), modified by Menlove (1974) and Culberson and Johnson (1982). All specimens were examined by TLC.

Table 1. Psora specimens used in this study with voucher information, major lichen substances, and GenBank accession numbers. New sequences are indicated by accession numbers in bold.

Taxon, specimen	Voucher information	Major lichen substances	GenBank accession number	
			ITS	mtSSU
P. altotibetica 1	*China, Xizang, Obermayer 5282* (GZU), holotype	gyrophoric acid	KU863638	KU863651
P. altotibetica 2	*China, Xizang, Miehe & Miehe 9573/23/02* (GZU), paratype	gyrophoric acid	KU863639	KU863652
P. altotibetica 3	*China, Xizang, Obermayer 5223* (GZU), paratype	gyrophoric acid	KU863640	KU863653
P. altotibetica 4	*China, Xizang, Obermayer 4365* (GZU), paratype	gyrophoric acid	KU863642	KU863655
P. altotibetica 5	*China, Xizang, Obermayer 3967* (GZU), paratype	gyrophoric acid	KU863641	KU863654
P. altotibetica 6	*China, Xizang, Obermayer 4485* (GZU), paratype	gyrophoric acid	KU863643	KU863656
P. californica	*USA, California, Timdal SON139/04* (O-L-60112)	bourgeanic acid, gyrophoric acid	EF524322	EF524292
P. elenkinii	*Russia, Yakutia, Haugan & Timdal YAK01/98* (O-L-18520)	no substances	**KY426119**	**KY426126**
P. globifera 1	*Greenland, Timdal 10149* (O-L-139171)	no substances	EF524323	EF524294
P. globifera 2	*Norway, Klepsland JK11-L619* (O-L-183774)	no substances	KU873928	–
P. globifera 3	*Norway, Bendiksby et al. 12914* (O-L-184327)	no substances	KU873930	–
P. globifera 4	*Norway, Klepsland JK11-L213* (O-L-177145)	no substances	KU873929	–
P. globifera 5	*Norway, Hjelmstad s.n.* (O-L-184143)	no substances	KU873932	–
P. himalayana 1	*Russia, Yakutia, Zhurbenko 98161* (M-0066792)	–	AY425635	–
P. himalayana 2	*Canada, Yukon, Rosentreter & McCune 17154* (O-L-184672)	no substances	**KY426120**	**KY426127**
P. hyporubescens	*USA, California, Bratt & Timdal 7052* (O-L-22483), holotype	anthraquinones, gyrophoric acid	EF524311	EF524295
P. indigirkae 1	*Russia, Yakutia, Haugan & Timdal YAK19/03* (O-L-19148), holotype	bourgeanic acid, gyrophoric acid	–	EF524302
P. indigirkae 2	*Russia, Yakutia, Haugan & Timdal YAK17/24* (O-L-19086), paratype	bourgeanic acid, gyrophoric acid	KU863631	KU863644
P. indigirkae 3	*Russia, Yakutia, Zhurbenko 92185* (O-L-118686), paratype	bourgeanic acid, gyrophoric acid	KU863632	KU863645
P. nitida	*Mexico, Baja California, Timdal SON33*/06 (O-L-15546)	gyrophoric acid	EF524313	EF524296
P. pacifica	*USA, California, Rosentreter 14580* (O-L-126265)	gyrophoric acid, unknown accessory	EF524314	EF524297
P. peninsularis	*Mexico, Baja California, Timdal SON32/07* (O-L-15539), holotype	norstictic acid	EF524320	EF524298
P. pseudorussellii	*Greece, Rui & Timdal 10998* (O-L-156015)	no substances	**KY426121**	**KY426128**
P. russellii 1	*Mexico, Baja California, Timdal SON31/03* (O-L-15531)	norstictic acid	EF524321	EF524300
P. russellii 2	*Mexico, Puebla, Rui & Timdal 7389* (O-L-22501)	norstictic acid	**KY426122**	**KY426129**

Taxon, specimen	Voucher information	Major lichen substances	GenBank accession number	
			ITS	mtSSU
P. russellii 3	*USA, California, Timdal SON131/02* (O-L-60087)	norstictic acid	**KY426123**	**KY426130**
P. taurensis 1	*Turkey, Halici* (ERCH-AMEKA 0.018), holotype	norstictic acid	**KY426124**	**KY426131**
P. taurensis 2	*Turkey, Timdal 7908* (O-L-203076), paratype	norstictic acid	**KY426125**	**KY426132**
P. tenuifolia 1	*Russia, Yakutia, Haugan & Timdal YAK17/26* (O-L-19088)	norstictic acid, zeorin	EF524309	EF524303
P. tenuifolia 2	*China, Xizang, Obermayer 4487* (GZU)	norstictic acid, zeorin	KU863636	KU863649
P. tenuifolia 3	*China, Xizang, Obermayer 5236* (GZU)	zeorin	KU863637	KU863650
P. testacea 1	*Greece, Rui & Timdal TH06/04* (O-L-59263)	atranorin	EF524315	EF524301
P. testacea 2	*Germany, Kainz 195* (M-0066793)	–	AY425636	–
P. testacea 3	*Germany, Kainz 192* (M-0066794)	–	AY425638	–
P. tuckermanii	*USA, Arizona, Rui & Timdal US240/05* (O-L-59926)	no substances	EF524317	EF524304
P. vallesiaca 1	*Greece, Rui & Timdal 7993* (O-L-15186)	norstictic acid	EF524324	EF524291
P. vallesiaca 2	*China, Xizang, Obermayer 3227* (GZU)	norstictic acid	KU863633	KU863646
P. vallesiaca 3	*China, Xizang, Obermayer 5279* (GZU)	no substances	KU863635	KU863648
P. vallesiaca 4	*Pakistan, Poelt K91-705* (GZU)	norstictic acid	KU863634	KU863647
P. vallesiaca 5	*Norway, Bendiksby et al. 12979* (O-L-184392)	norstictic acid	KU873926	–
P. vallesiaca 6	*Norway, Klepsland JK11-L624* (O-L-183778)	norstictic acid	KU873927	–
P. vallesiaca 7	*Norway, Klepsland JK11-L601* (O-L-183760)	norstictic acid	KU873931	–

DNA extraction, PCR and sequencing

We performed DNA extraction, PCR amplification, PCR purification, and cycle sequencing as described by Bendiksby and Timdal (2013). DNA was extracted from apothecia of 7 specimens (Table 1; GenBank Accession Numbers KY426119–KY426132). All DNA isolates produced for the present study are deposited in the DNA collection at Natural History Museum, University of Oslo or Molecular Biology Lab of Erciyes University, Faculty of Science (only *P. taurensis* 1). We amplified and sequenced the ITS and the mtSSU using the primer pairs ITS5/ITS4 (White et al. 1990) and mtSSU1/mtSSU3R (Zoller et al. 1999), respectively.

Data analyses

Sequences were assembled and edited using SEQUENCHER v.4.1.4 (Gene Codes Corporation, Ann Arbor, Michigan, U.S.A.). Alignments were established in BIOEDIT 7.2.3 (Hall 1999) using the "ClustalW/Multiple alignment" option with subsequent manual adjustments. We analysed and summarized the data with parsimony and Bayesian phylogenetic methods, including model testing, as described in Bendiksby et al. (2015). As configuration settings in PartitionFinder v.1.1.1 (Lanfear et al. 2012),

we used linked branch lengths, data blocks according to named genetic region (i.e. ITS1, 5.8S, ITS2, mtSSU), the greedy search scheme, the Bayesian information criterion as selection metric and only models that are implemented in MrBayes 3.1.2 (Huelsenbeck and Ronquist 2001, Ronquist and Huelsenbeck 2003). The nuclear and mitochondrial datasets were analysed separately and in combination (concatenated) with indels treated as missing data.

Results

Anatomy

The following key characters for including *P. taurensis* in *Psora* were observed in the new species: the upper cortex contained remnants of algae throughout both the lower stainable layer and the upper epinecral layer ('Scheinrindentyp' of Poelt 1958); the hypothecium contained calcium oxalate crystals; the epihymenium contained orange crystals which dissolved in K with a purple diffusion (assumed to be anthraquinones); and the ascus contained a well-developed, amyloid tholus with a central, deeper amyloid tube structure (*Porpidia*-type).

The following species level characters were observed in *P. taurensis*: Upper cortex composed of thick-walled hyphae with angular to rounded lumina; crystals of norstictic acid and calcium oxalate present in medulla; no crystals in upper cortex; poorly developed lower cortex; ascospores 11–16 × 5.5–7 µm.

Secondary chemistry

The results of the TLC examinations are given in Table 1. The two specimens of *P. taurensis* contained norstictic acid.

Alignments and phylogenetic analyses

Altogether 14 DNA sequences were generated from 7 specimens for the present study (7 ITS and 7 mtSSU; Table 1). The ITS end-trimmed alignment of 41 accessions was 573 basepairs long and contained 236 parsimony-informative characters. The corresponding numbers for the mtSSU matrix of 32 accessions was 794 and 22, respectively. For ITS1, ITS2 and mtSSU, the HKY+I+G model gave the best fit, whereas K80+I+G had the estimated best fit for 5.8S. Tree-topologies from both parsimony and Bayesian analyses of ITS vs mtSSU alignments were congruent but resolved to various extents (not shown). Final analyses were therefore performed on a concatenated dataset of 1367 bp. In the Bayesian analysis, the average standard deviation of split frequencies (ASDSF) had fallen to 0.004765 at termination (five million generations) and the first

1500 saved trees (i.e. 30%) were discarded as burn-in, ensuring that only generations with ASDSF below 0.01 were kept for summarizing. The Bayesian 50% majority rule consensus tree is presented as an unrooted tree with both Bayesian posterior probability (PP > 0.9) and parsimony jackknifing (JK > 90) branch support superimposed (Fig. 1). Multiple accessions of all species group to the respective species with high support. The single exception is a clade consisting of two accessions of *P. himalayana* that is nested within the *P. vallesiaca–himalayana* clade, grouping with high support with *P. vallesiaca* (Schaer.) Timdal 4–7 to the exclusion of *P. vallesiaca* 1–3. *Psora tenuifolia* Timdal is strongly supported as sister to the new species, *P. taurensis*. The *P. tenuifolia–taurensis* clade is sister to *P. altotibetica*, which in turn is sister to the *P. vallesiaca–himalayana* clade. A clade consisting of *P. hyporubescens* Timdal and *P. pacifica* Timdal is also strongly supported. The sister relationship between *P. californica* Timdal and *P. indigirkae* Timdal & Zhurb. received low support (JK=57; PP=0.51). *Psora globifera* (Ach.) A.Massal. is supported as sister to the *P. altotibetica–tenuifolia–taurensis–vallesiaca–himalayana* clade, but this relationship was not supported by parsimony jackknifing. The same accounts for the grouping of the *P. hyporubescens–pacifica* clade with the aforementioned multispecies clade. Apart from this, the molecular data support no further inter-species relationships.

Discussion

Our molecular data strongly support *Psora taurensis* as a distinct evolutionary unit and, given the current taxon sampling, *P. tenuifolia* is its sister (Fig. 1). *Psora tenuifolia* differs in having thinner, generally more ascending squamules containing zeorin (and often norstictic acid, as *P. taurensis*) and in having a well-developed lower cortex composed of mainly anticlinally oriented hyphae which are densely covered by calcium oxalate crystals (cf. Timdal 1986). *Psora tenuifolia* is known from winter-cold, arid sites in Alaska and arctic Canada (Timdal 1986), Yakutia (Zhurbenko 2003), and the Great Himalayas (Timdal et al. 2016).

Psora altotibetica, which falls out as sister to the *P. tenuifolia–taurensis* clade (Fig. 1), differs in having strictly adnate squamules which are more evenly covered by pruina and in containing gyrophoric acid (cf. Timdal et al. 2016). *Psora altotibetica* is known only from the Great Himalayas between 4230 and 5000 m altitude (Timdal et al. 2016).

Outside that clade is the complex of *P. vallesiaca*, which consists of several strongly supported subclades with varying branch lengths and with *P. himalayana* embedded (Fig. 1). *Psora himalayana* and *P. vallesiaca* are distinguished mainly on the thallus chemistry, i.e. no lichen substances in the former and norstictic acid in the latter. Timdal et al. (2016) indicated that they may be conspecific, based on only the ITS sequence of a single specimen of *P. himalayana* (from Yakutia), which rendered it as nested within a clade of seven accessions of *P. vallesiaca*. In the present study, both ITS and mtSSU sequences of a second specimen of *P. himalayana* (from Yukon) is provided. The two specimens of *P. himalayana* group with moderate support (JK=81;

Figure 1. Bayesian 50 % majority rule consensus tree based on a concatenated alignment of ITS and mtSSU sequences of 42 accessions of 17 *Psora* species (see Table 1). Parsimony jackknife support values above 90% are shown below branches and Bayesian posterior probabilities above 0.9 above. The curly branch leading to *P. testacea* has been shortened to reduce the size of a broad figure.

PP=1), and the species remains nested in the *P. vallesiaca* complex (Fig. 1). A broader sampling is needed, however, especially from the Himalayas, before *P. himalayana* may be synonymised with *P. vallesiaca*. The complex differs morphologically from *P.*

taurensis mainly in forming more distinctly white-edged squamules with a more upturned margin.

Psora elenkinii was synonymized with *P. himalayana* by Timdal (1986). However, the ITS and mtSSU sequences provided here, from a morphologically typical specimen from Yakutia, shows that the species falls outside the *P. vallesiaca–himalayana* clade (Fig. 1). The species is hence accepted here.

The North American desert lichen *P. russellii* differs morphologically from *P. taurensis* mainly in forming closely adnate squamules with a more down-turned margin and often with a regular, central depression, and in having medium brown apothecia. The species contains norstictic acid both in the upper cortex and in the medulla and there is also sometimes a trace of gyrophoric acid (Timdal 1986). The three sequenced specimens of *P. russellii* group with high support and are not closely related to *P. taurensis* (Fig. 1).

Psora pseudorussellii differs from *P. russellii* mainly in lacking lichen substances and in forming smaller, more elongated squamules without a central depression (Timdal 1986). It differs from *P. taurensis* mainly in lacking lichen substances and in the medium brown colour of the apothecia. This essentially eastern North American species was reported new to Europe from Greece (Crete) by Grube et al. (2001). We have examined additional European specimens from Greece (Crete and Samos), Italy (Calabria), and Spain (Granada, Madrid, and Soria) (Timdal unpubl.), and here provide DNA sequences from the species for the first time. Phylogenetically it is not closely related to *P. taurensis* (Fig. 1).

Psora peninsularis Timdal, occurring in coastal scrubs and Sonoran desert in southern California and Baja California, differs morphologically mainly in forming castaneous brown, shiny, epruinose squamules. It contains norstictic acid in the medulla (Timdal 2002). Phylogenetically it is not closely related to *P. taurensis* (Fig. 1).

Two additional species are relevant for the discussion of the taxonomy of *P. taurensis*: *P. gresinonis* B.de Lesd. and *P. subrubiformis* (Vain.) Dzhur. Lack of sequence data makes this discussion purely morphological. We know the former species from c. 15 localities in Mediterranean Europe and Central Asia and the latter only from the type collection from Turkmenistan (Timdal 1984, Timdal unpubl.). *Psora gresinonis*, which often contains norstictic acid like *P. taurensis*, differs in forming smaller, thinner, more rounded and concave squamules with a non-pruinose, brown or sometimes greyish margin. The holotype of *Psora subrubiformis* lacks lichen substances and differs from *P. taurensis* in having persistently plane to only weakly convex, densely white pruinose apothecia (cf. Timdal 1984) and a thallus morphology resembling that of the *P. vallesiaca* complex. Except for the more plane apothecia, there are few arguments for regarding it as a distinct species within the the *P. vallesiaca* complex.

Hence, since *P. taurensis* is now known from two localities and its distinctness is supported by various data, we hereby describe it as a new species.

Taxonomy

***Psora taurensis* Timdal, Bendiksby, Kahraman & Halıcı, sp. nov.**
Mycobank: MB820063
Fig. 2

Diagnosis. Morphologically most similar to *Psora russellii*, but squamules more ascending and lacking a central depression, and apothecia brownish black. Phylogenetic sister species of *P. tenuifolia*, but having a thicker, more adnate thallus with a poorly developed lower cortex and lacking zeorin.

TYPE. TURKEY. Mersin: Gülnar-Silifke Highway, exit of Kayrak , 36°21'24.5"N, 33°33'08.8"E, 1000-1020 m alt., on soil on calcareous bedrock, 12 Apr 2012, M.G. Halıcı (holotype: ERCH-AMEKA 0.018!)

Description. Thallus squamulose; squamules up to 8 mm wide, rounded, adnate with ascending margin to imbricate, becoming deeply lobed, concave; upper surface medium brown, dull, pruinose in the outer part of the lobes, with regular fissures in the cortex; margin first concolorous with upper side, soon becoming white by pruina, straight or somewhat up-turned; upper cortex up to 130 µm thick, including an up to 20 µm thick epinecral layer, composed of thick-walled hyphae with angular to rounded lumina, not containing crystals, containing remnants of algae throughout (chlor-zinc-iodine!); algal layer continuous, 30–45 µm thick; medulla not amyloid, containing lichen substances (K+ yellow, red crystals precipitating) and calcium oxalate; lower cortex poorly developed; lower surface white to pale brown. Apothecia up to 1.5 mm diam., laminal or submarginal on the squamules, weakly convex and indistinctly marginate when young, soon becoming strongly convex and immarginate, brownish black, epruinose. Proper exciple yellowish brown in the rim, colourless in inner part, lacking crystals, composed of radiating, thick-walled hyphae; hypothecium colourless in lower part, pale brown in upper part, containing crystals of calcium oxalate; epihymenium yellowish brown, containing orange crystals dissolving in K, K+ purple; hymenium 70–90 µm high, colourless, amyloid. Paraphyses straight, thin-walled, moderately conglutinated, sparingly branched and anastomizing, with a slightly swollen apical cell. Ascus clavate, with a well-developed, amyloid tholus containing a deeper amyloid tube, lacking an ocular chamber (*Porpidia*-type); ascospores ellipsoid, non-septate, hyaline, 11–16 × 5.5–7 µm (n = 20). Conidiomata unknown.

Chemistry. Norstictic acid (by TLC); medulla K+ yellow turning red, C–, KC–, P+ orange.

Habitat and distribution. The species is known from two localities in Turkey, both at c. 1000 m altitude. Both sites are in areas with Mediterranean climate. The holotype was collected in a rocky area with scrub vegetation derived by forest degradation; the paratype grew in an open pasture. Both specimens were terricolous, the holotype grew on soil over limestone.

Figure 2. *Psora taurensis*, habitus. A, part of holotype; B, part of paratype. Scale bar = 2 mm.

Etymology. The name refers to its occurrence in the Taurus Mountains.

Other specimen examined. Turkey. Antalya: along the road a few km SE of Gündoğmuş, 36°48.1'N, 32°00.3'E, 1000 m alt., on soil in open pasture, 24 Apr 1994, E.Timdal 7908 (O L-203076, paratype).

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